aerosol direct radiative forcing

on the consistency of estimates from global modelling and observation-tied methods

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Background

- **anthropogenic climate change** (since pre-industrialization)
  - **at ToA**
    - greenhouse gases: + 2.3 W/m2
    - aerosol direct effect: - (0.0 to 0.7) W/m2
    - aerosol indirect effs: - (0.5 to 1.3) W/m2
- **aer. direct effect uncertainty is surprisingly large**
  - **modeling**
    - IPCC- TAR 0.43 W/m2
    - IPCC- 4AR 0.20 +/-0.20 W/m2 [AeroCom]
  - **remote sensing tied techniques**
    - several studies 0.55 +/-0.20 W/m2

Questions - Approach

- **Questions**
  - **Why are differences so large for aerosol direct forcing of data-tied approaches ?**
  - **Why are the new (direct) aerosol cooling estimates from global modeling so much weaker than from data-tied approaches ?**
- **Approach**
  - **understand what aerosol and environmental data and what global coverage relate to the estimate**
  - **compare beyond annual global averages - investigate on a regional and seasonal basis**

direct ToA forcing ingredients

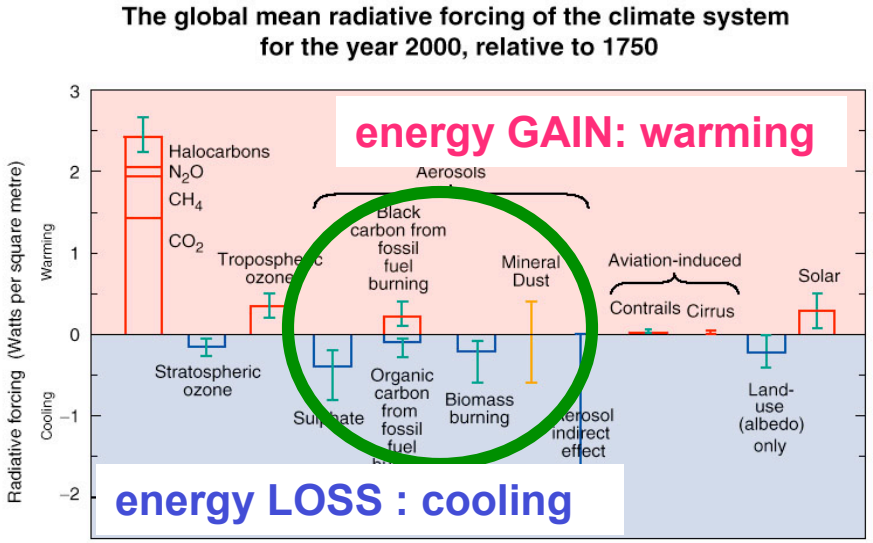
…with many opposing influences: inconsistencies cause uncertainty!

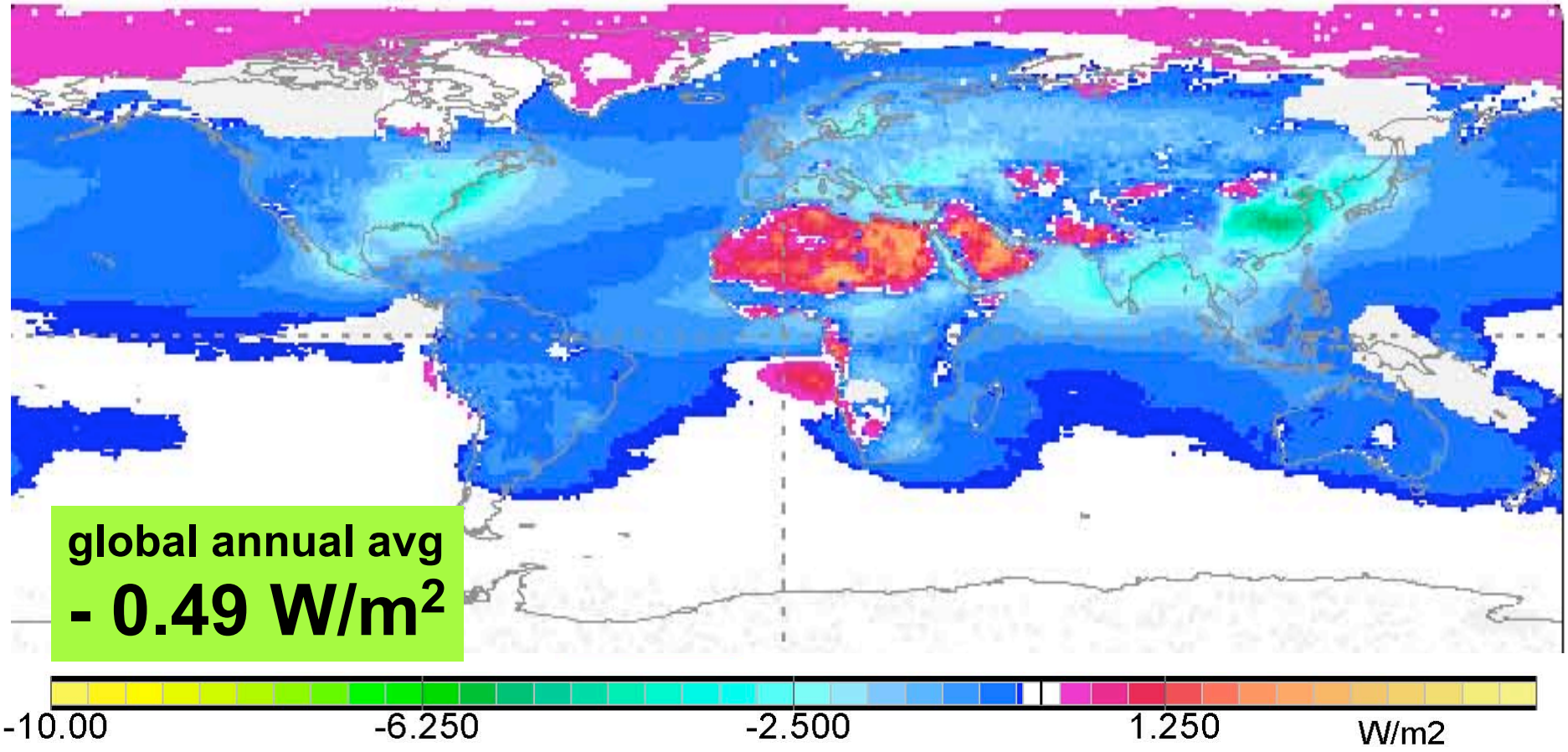
- **aerosol properties**
  - **aot (aerosol amount)** — with more aot: stronger impact
  - **ssa (aero absorption)** — with more absorption: less negative
  - **g (aerosol size)** — with smaller scatterers: stronger im.
- **environmental properties**
  - **available sun light** — with more insolation: stronger im.
  - **solar surface albedo** — with higher albedo: less negative
  - **cloud co-location** — with cloud above: reduced impact
  - **rel. altitude to clouds** — with clouds below: less negative
  - **sun-elevation** — scattering: max impact at mid angle
  - **temp. (sur. /profile)** — secondary effect for natural aerosol
  - **anthropogenic fraction** — estimates from modeling needed !

my estimate

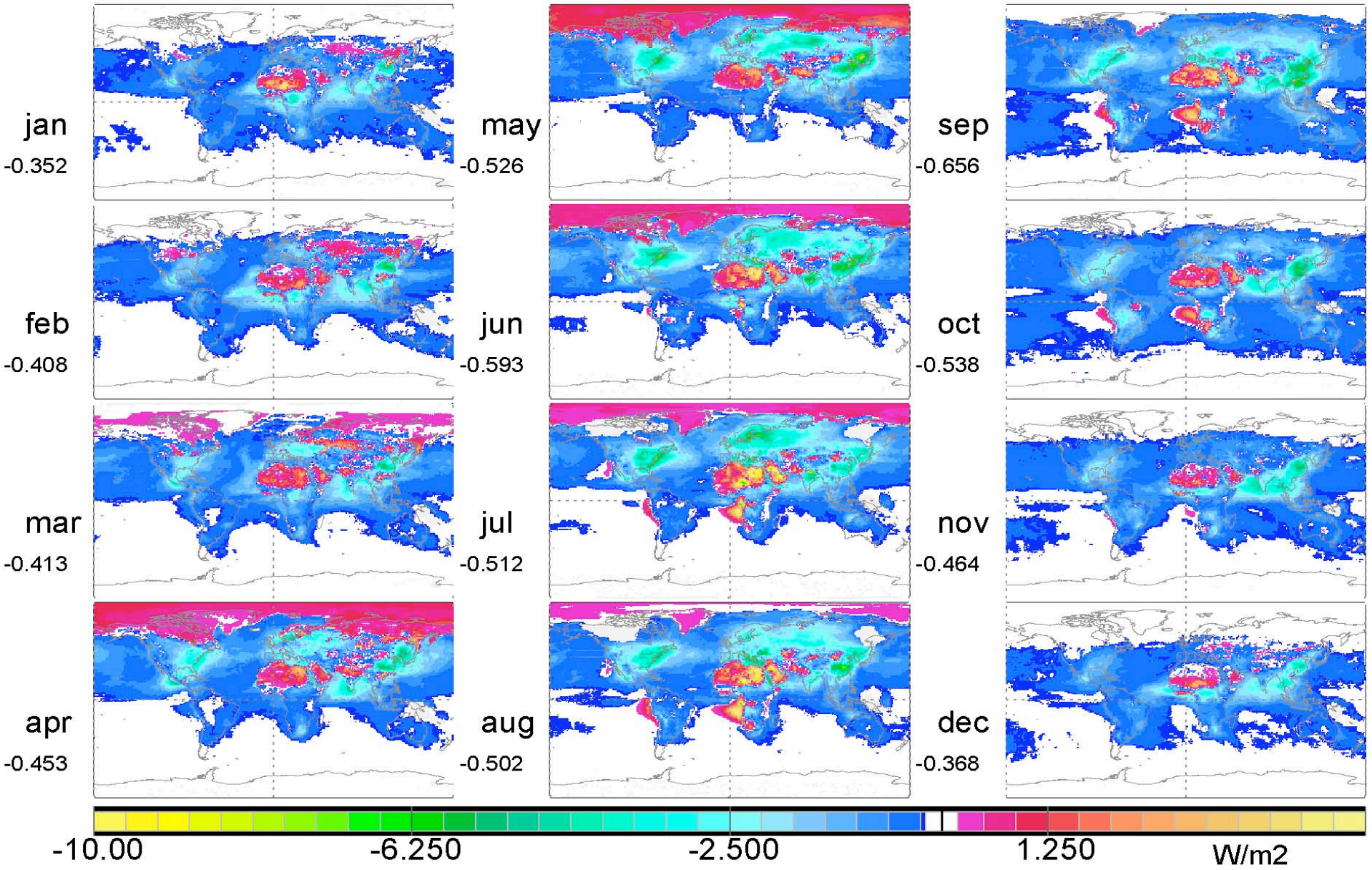
for **the direct aerosol forcing**

at the top of atmosphere (ToA)
with clouds (all-sky conditions)
for anthropogenic aerosol





aerosol dir forcing - on a monthly basis

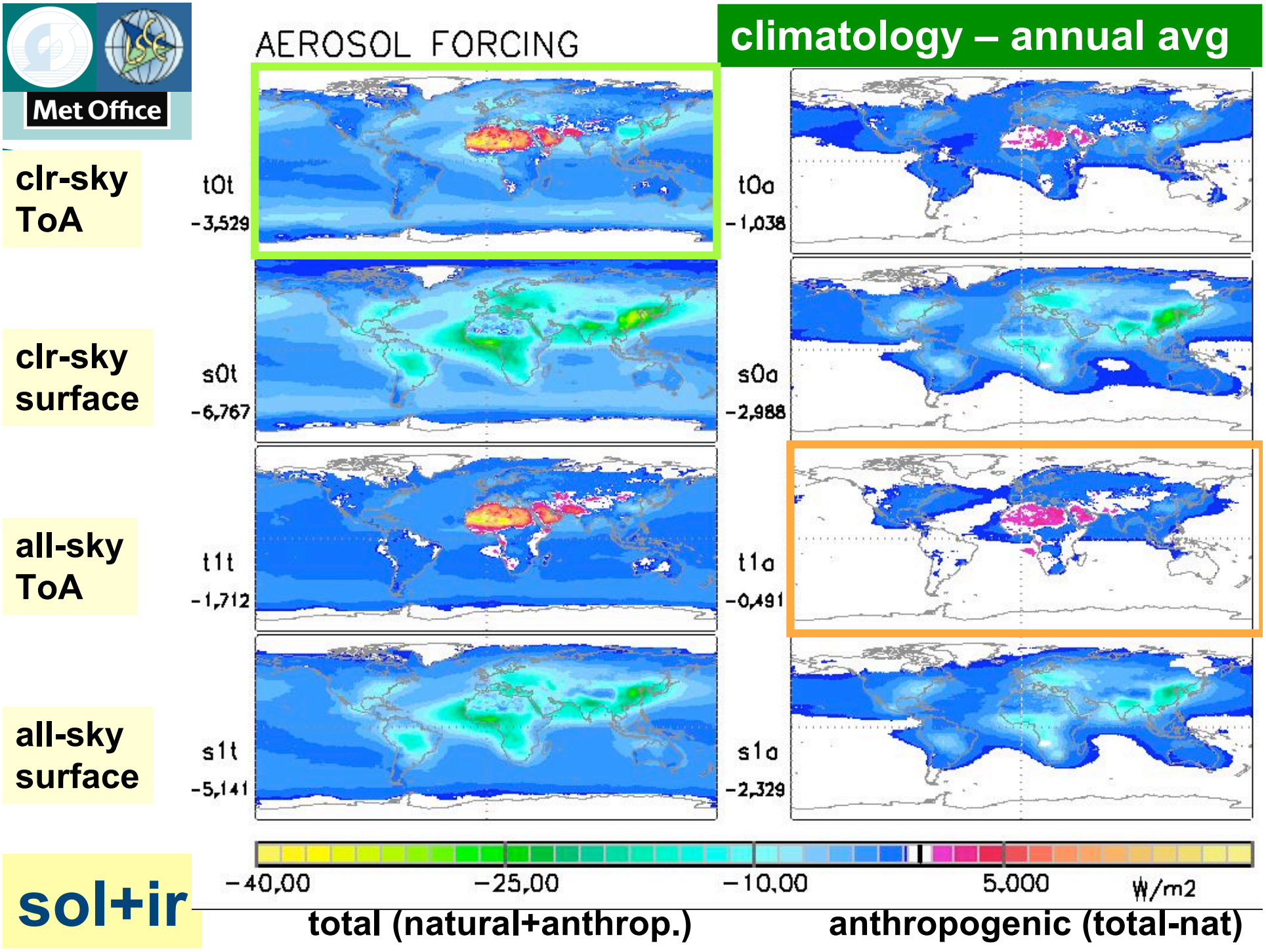


other aerosol rad. forcings

- location
  - ToA, atm, surface
- environment
  - all-sky, clear-sky
- spectral range
  - solar, infrared, both

Forcing	sol,ir	sol,ir	solar	solar
W/m²	clear-sky	all - sky	clear-sky	all - sky
ToA	- 3.5	- 1.7	- 4.5	- 2.3
surf.	- 6.8	- 5.1	- 9.2	- 6.7
ToA, an	- 1.0	- 0.5	- 1.1	- 0.5
surf, an	- 2.9	- 2.3	- 3.2	- 2.5

- on a globally avg basis:
  - at clear-skies: surf forcing ~ 2 * ToA forcing (⇨ atm ~ ToA)
  - at all-skies: surf forcing ~ 3 * ToA forcing (⇨ atm ~ 2*ToA)
  - solar effects dominate infrared effects (9:1 at ToA, 4:1 at surf)
  - cloud effect (all-sky *minus* clear-sky): ToA forcing is ~ halved


AEROSOL FORCING
climatology – annual avg
clr-sky ToA
clr-sky surface
all-sky ToA
all-sky surface
sol+ir
t0t
-3,529
t0a
-1,038
s0t
-6,767
s0a
-2,988
t1t
-1,712
t1a
-0,491
s1t
-5,141
s1a
-2,329
-40,00
-25,00
-10,00
5,000
W/m2
total (natural+anthrop.)
anthropogenic (total-nat)

what is the input to these #s ?

- aerosol properties
  - complete (1*1) monthly fields from global modeling
  - improved with quality data from AERONET
  - ‘smart’ assumptions (mid-visible ➔ broadband)
- environmental properties
  - MODIS surface albedo (visible and near-IR)
  - ISCCP cloud (high-, mid- and low- cover, scene ot)
    - from global modeling:
  - aerosol altitude distribution (rel. to clouds)
  - anthropogenic fine mode (r<0.5μm) fraction

aerosol properties

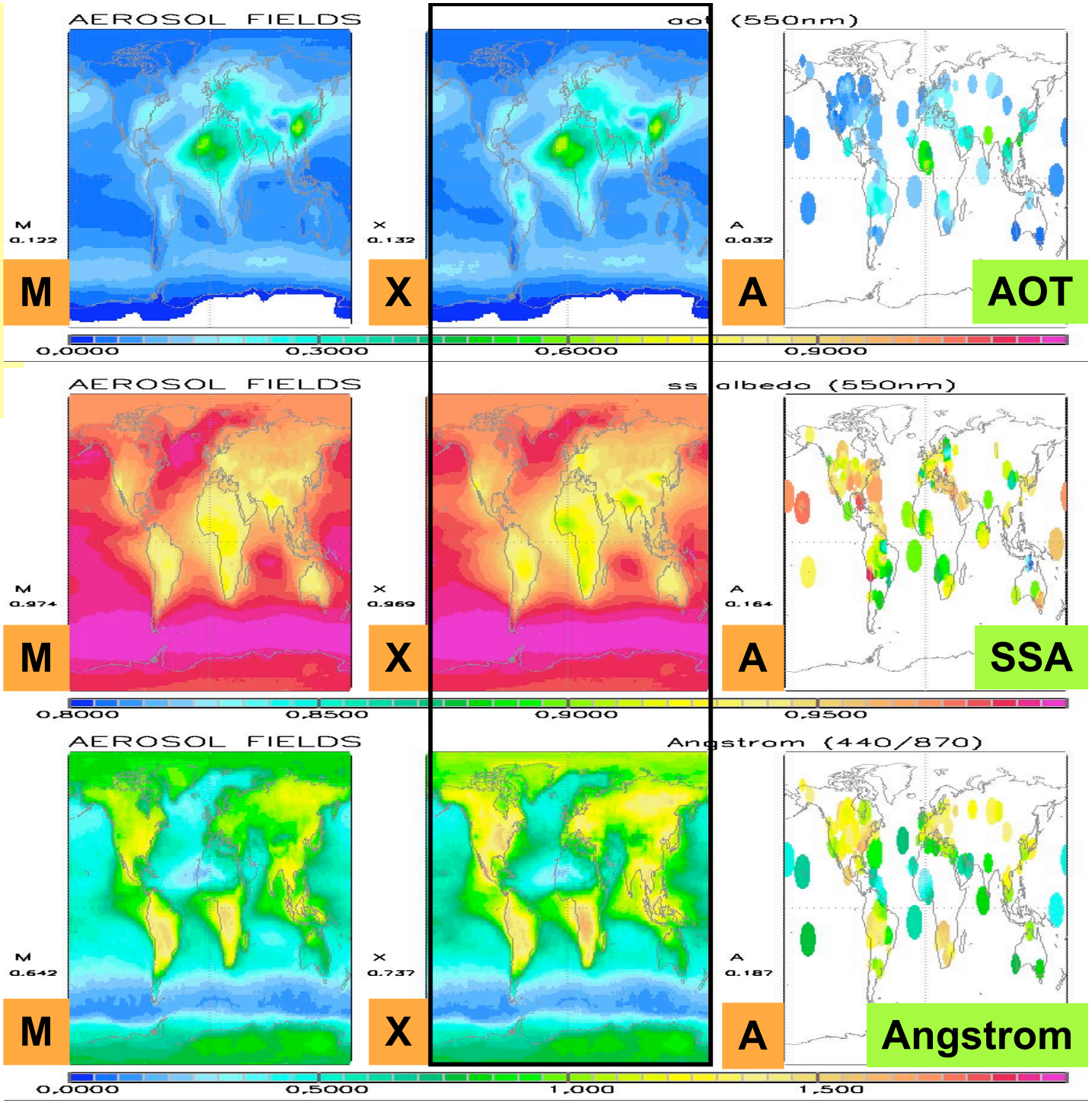
AeroCom median and AERONET

- **M**

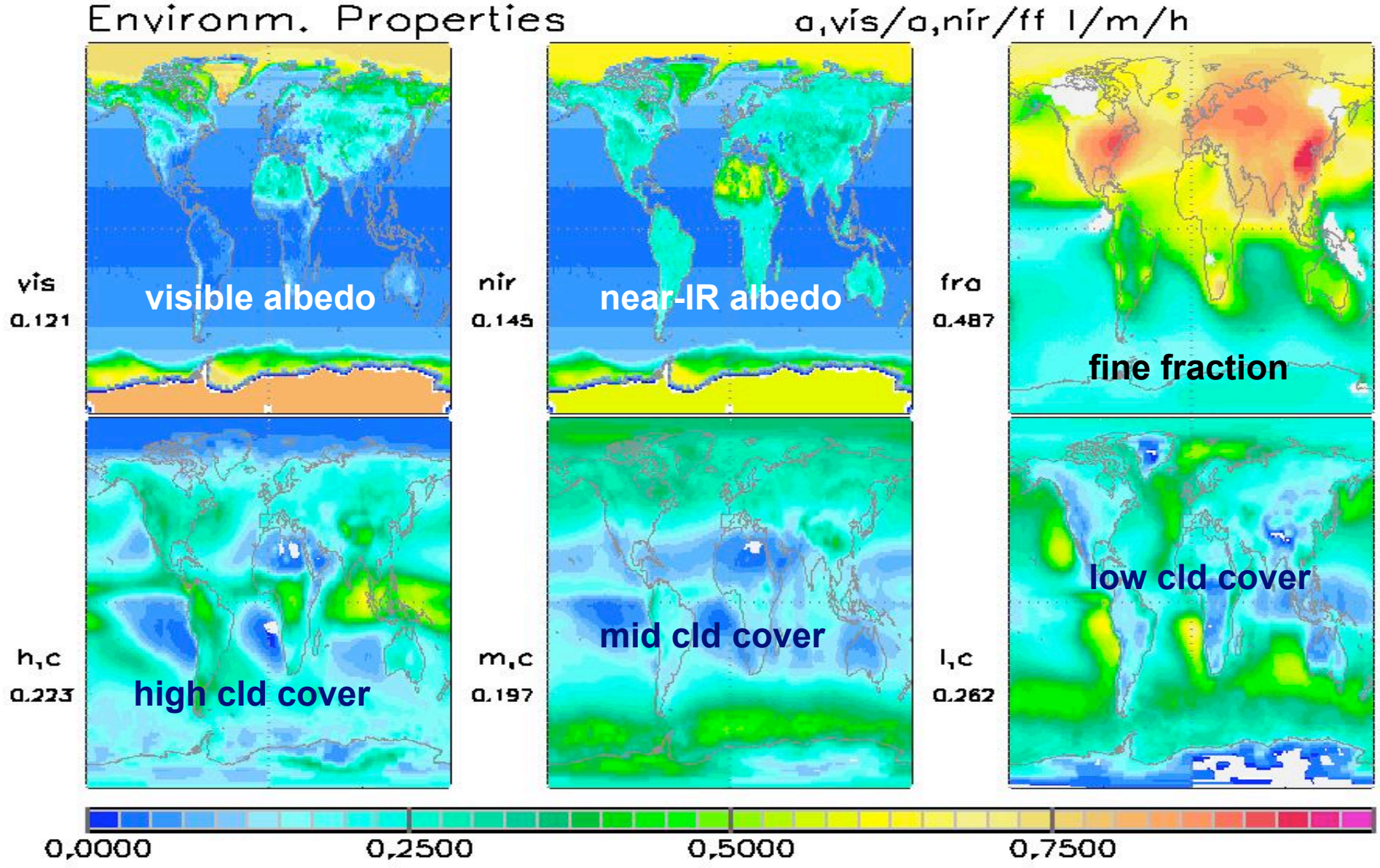
  AeroCom model median
- **X**

  merged product
- **A**

  AERONET (enlarged)



environmental prop choices



- 0.49W/m^2 - consistent with other est?

NO !

- **data-tied efforts**
  - **- 0.44 W/m2** median model
  - **- 0.49 W/m2** median model + merged AERONET
  - **- 0.60 W/m2** $FE_{,merged}$ applied to sat composite
  - **- 0.35 W/m2** Chung et al.
  - **- 0.70 W/m2** Quaas et al.
  - **- 0.75 W/m2** Bellouin et al.
  - **- 0.50 W/m2** Hayward et al.
  - **- 0.46 W/m2** Kaufman et al.

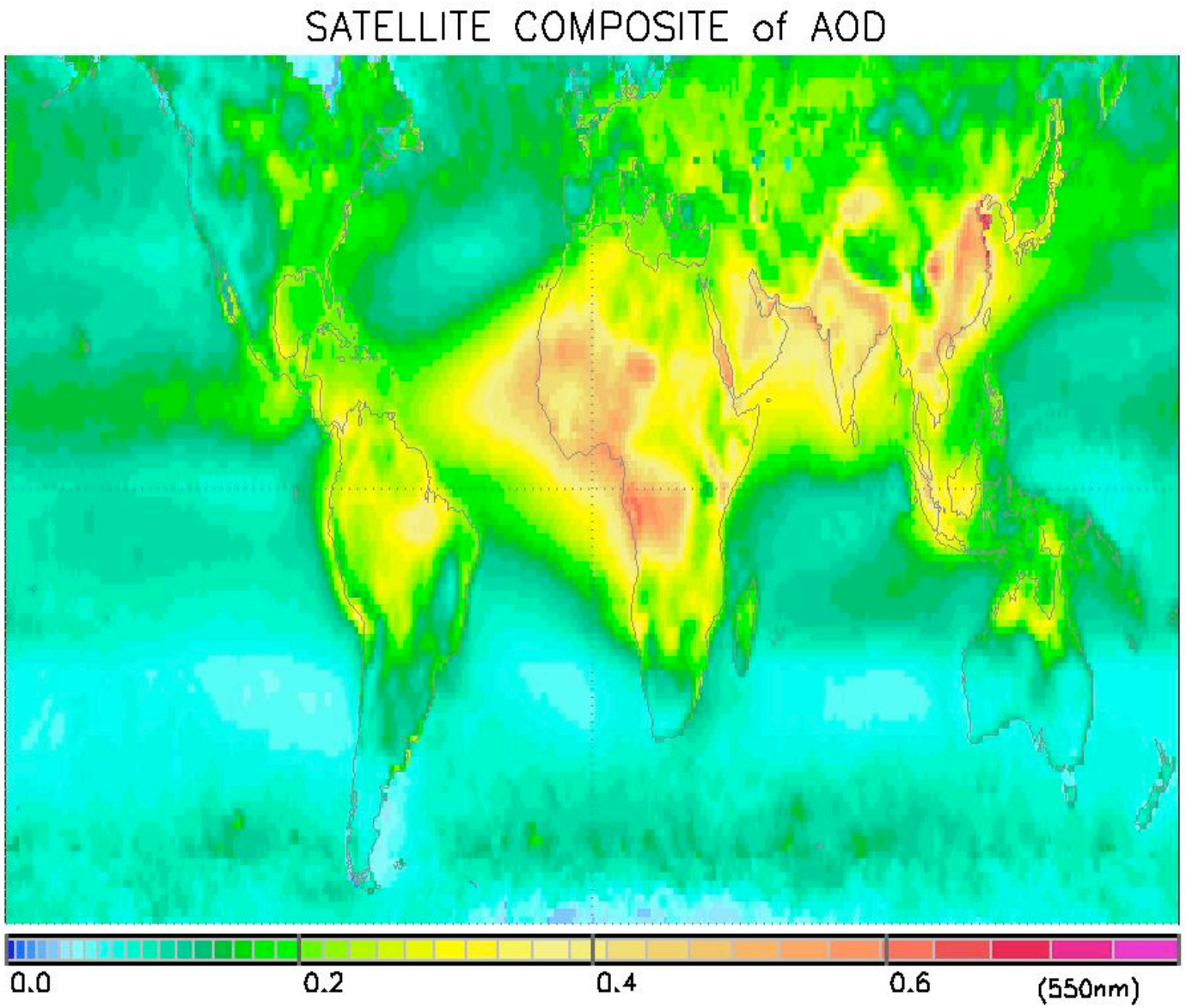
WARNING
many of these 'data'-estimates are not based on global coverage

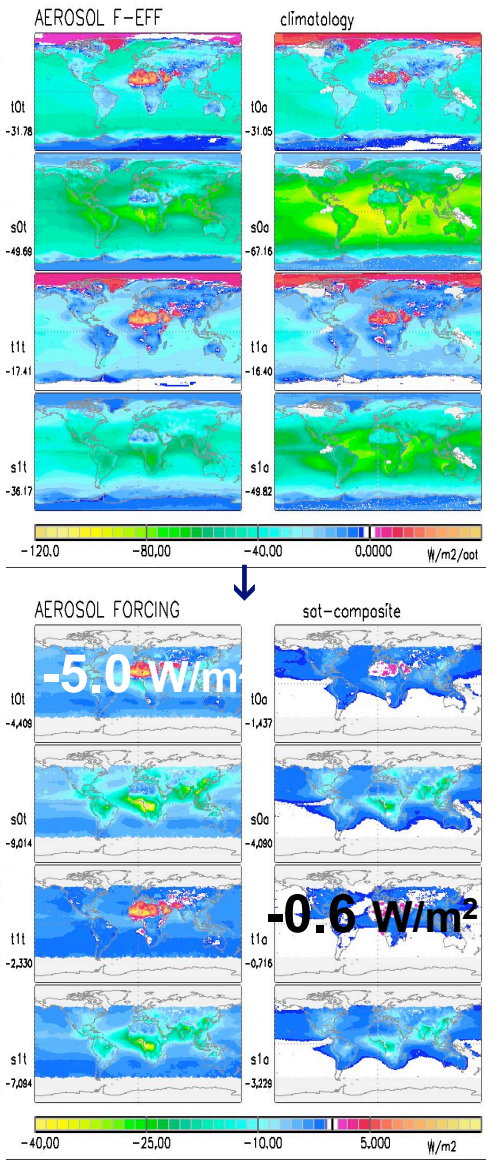
- **global modeling efforts**
  - **- 0.43 W/m2** IPCC –TAR
  - **- 0.18 W/m2** AeroCom avg. **+/- 0.2 W/m2**
  - **- 0.35 W/m2** LOA-model

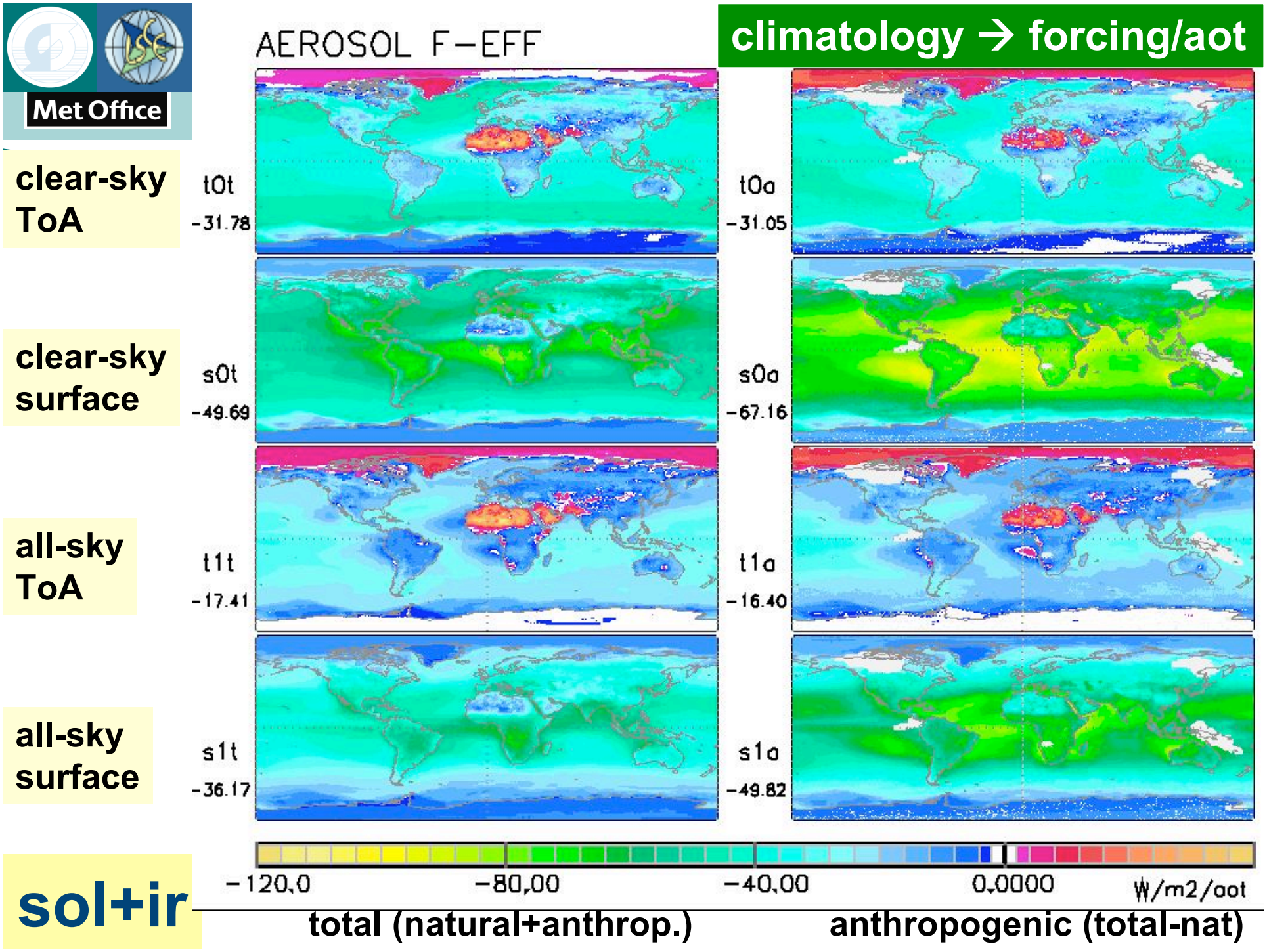
compare forcings

- **Participant # 1**
  - combine calculated forcing efficiency fields (F/aot) with composite of regionally 'best' satellite data
- **Participant # 2**
  - the Quaas approach, relating changes in MODIS-aot to changes in CERES broadband solar fluxes
- **Participant # 3**
  - the average forcing of simulations with 9 different global models, as part of a AeroCom exercise
- **Participant # 4**
  - use optical properties of AeroCom in offline calcu.

1 aot (sat composite) * FE



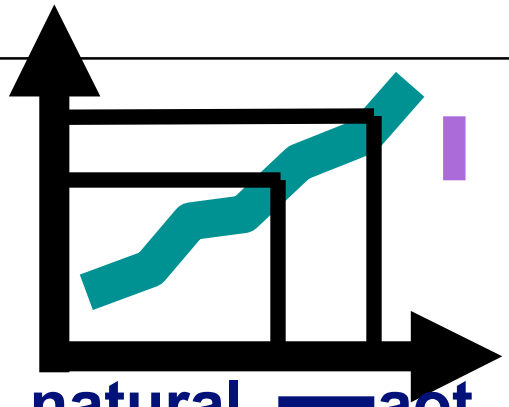



AEROSOL F-EFF
climatology → forcing/aot
clear-sky ToA
clear-sky surface
all-sky ToA
all-sky surface
sol+ir
t0t
-31.78
t0a
-31.05
s0t
-49.69
s0a
-67.16
t1t
-17.41
t1a
-16.40
s1t
-36.17
s1a
-49.82
-120.0
-80.00
-40.00
0.0000
W/m2/aot
total (natural+anthrop.)
anthropogenic (total-nat)

#2 the 'Quaas' data effort

albedo
albedo
total
natur.

not over deserts or ice
only for good statistics

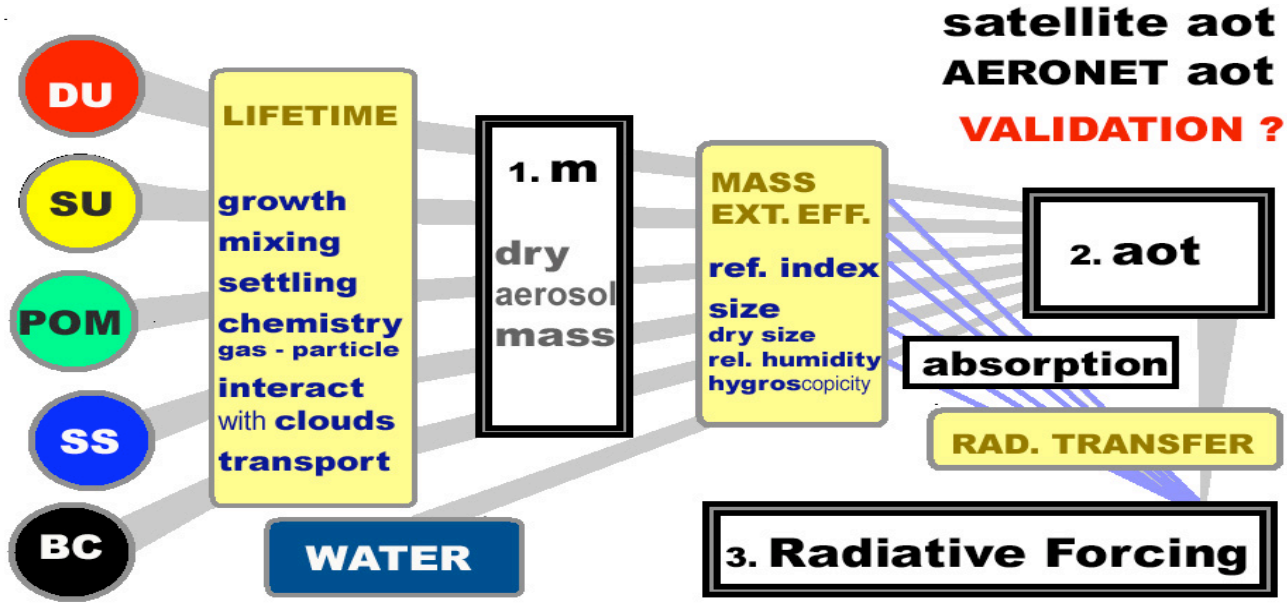


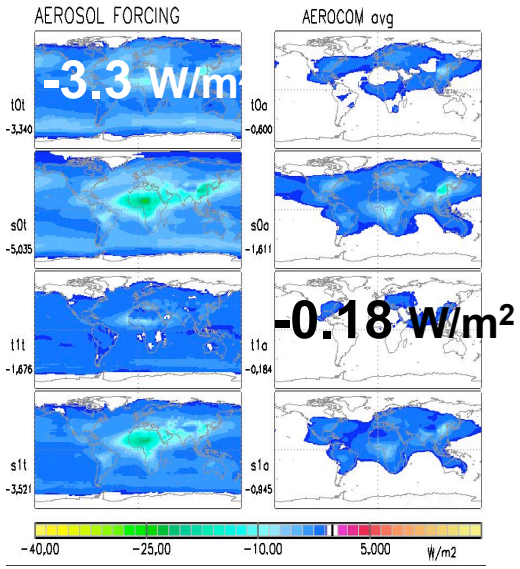
- relate MODIS aerosol and cloud prop in CERES footprint to CERES broadband fluxes
- stratify by cloud fraction and LWC at 1°lat*1°lon
- associate changes in aerosol (MODIS) to changes in broadband fluxes (CERES)
- extract the anthropogenic impact with data on aot anthropogenic fraction from global modeling

#3 the AeroCom average

aerosol model intercomparison project http://nansen.ipsl.jussieu.fr/AEROCOM/

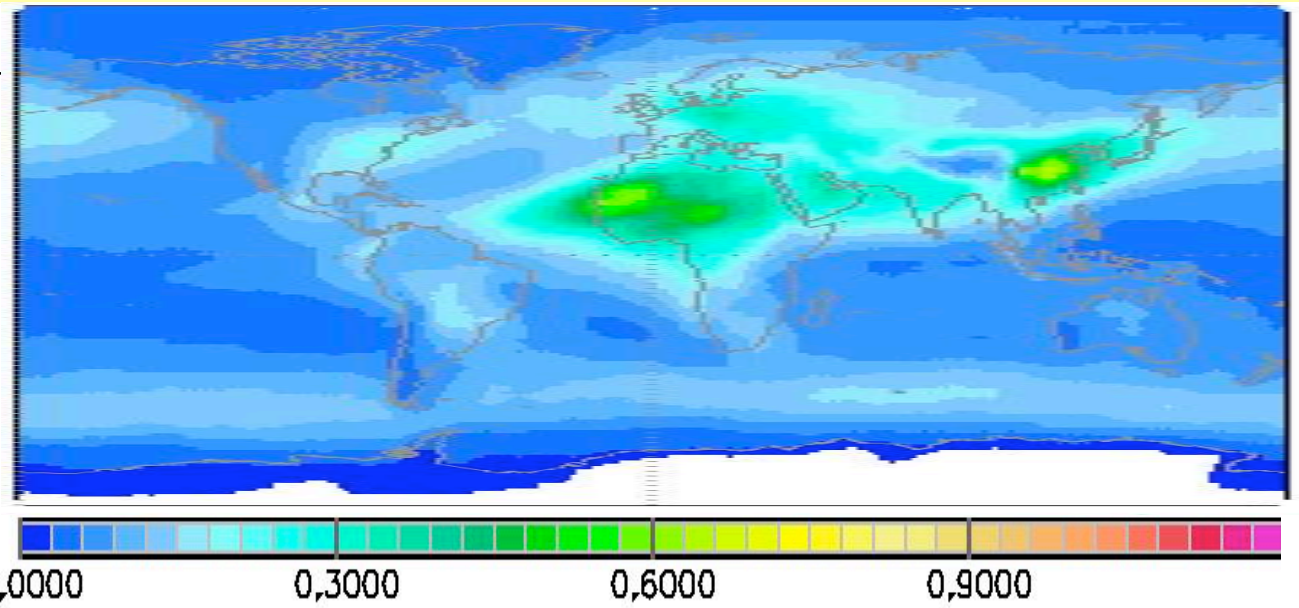
- 9 models participated
  - 1.simulation: apply AeroCom year 2000 emissions
  - 2.simulation: apply AeroCom year 1750 emissions
- total forcing: results of 'sim1'
- anthrop. forcing: differences of 'sim1' minus 'sim2'



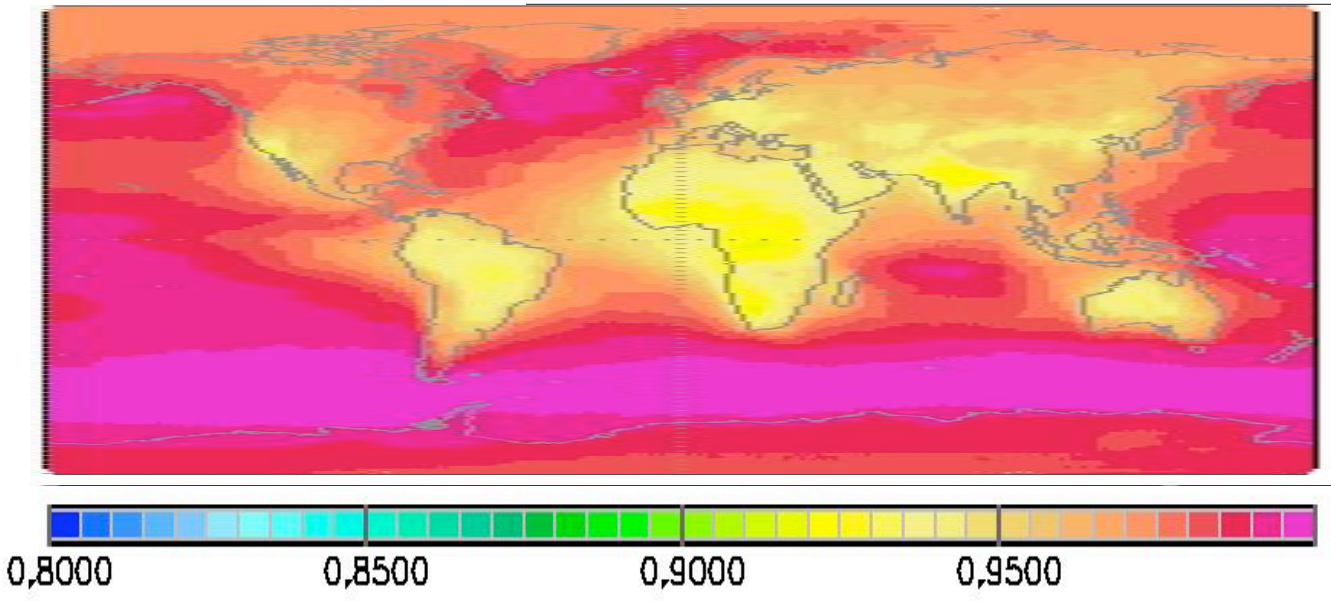


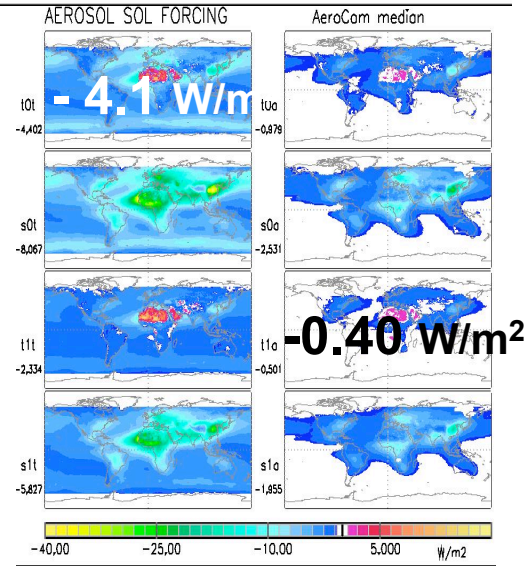
#4 AeroCom median data

aot

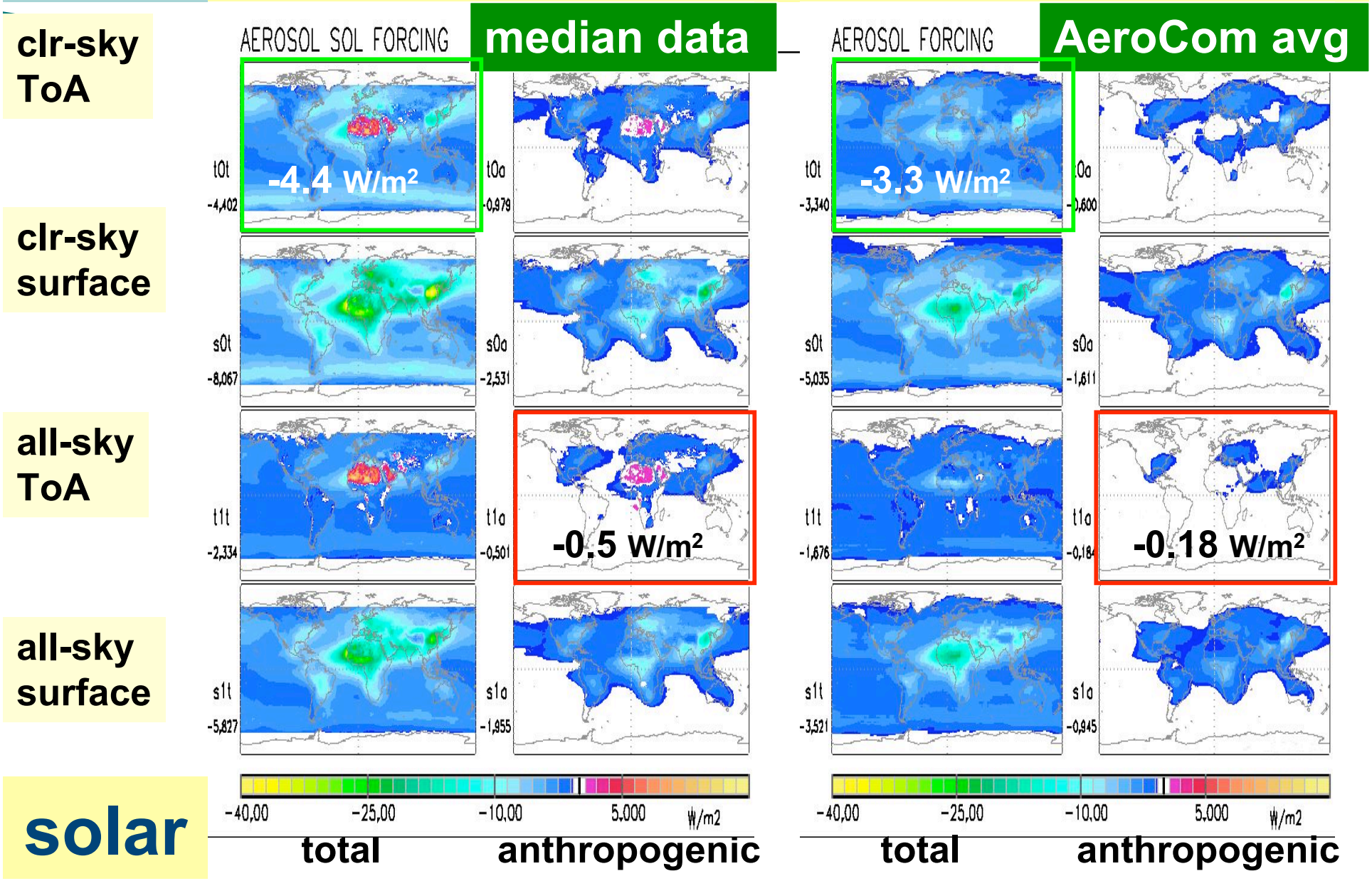


ssa



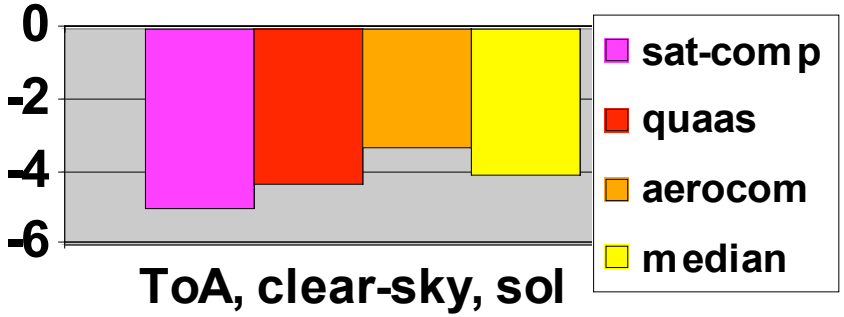


off-line vs. on-line



global ann solar ToA forcings (W/m²)

- clr-sky, total (nat+ant)



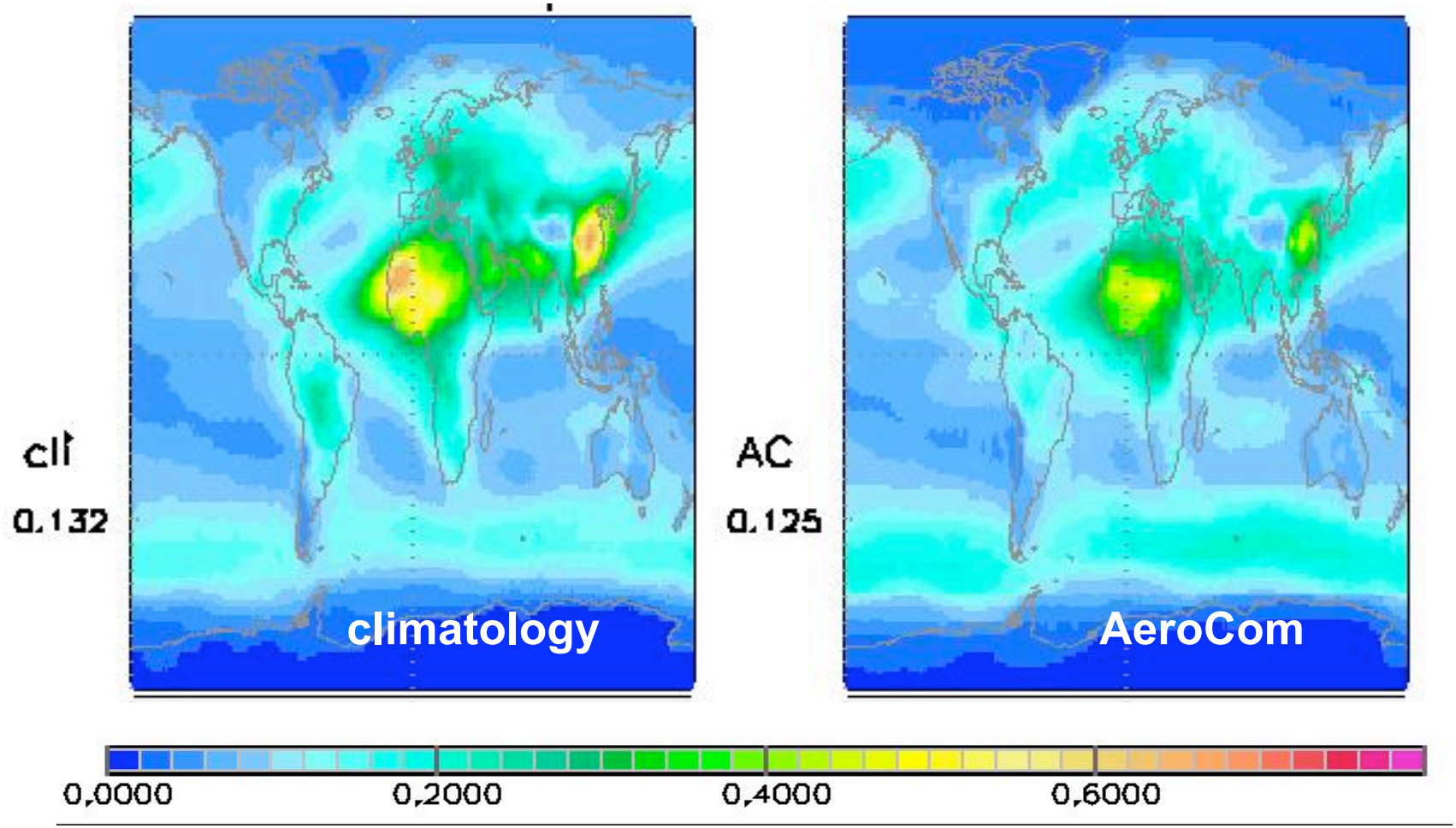
- median agrees with obs !
- sat-comp aot-biased high
- aerocom is already low (?)

values refer to complete coverage (scaling with median for missing data)

  - why ?
  - investigate diff of properties among median and aerocom

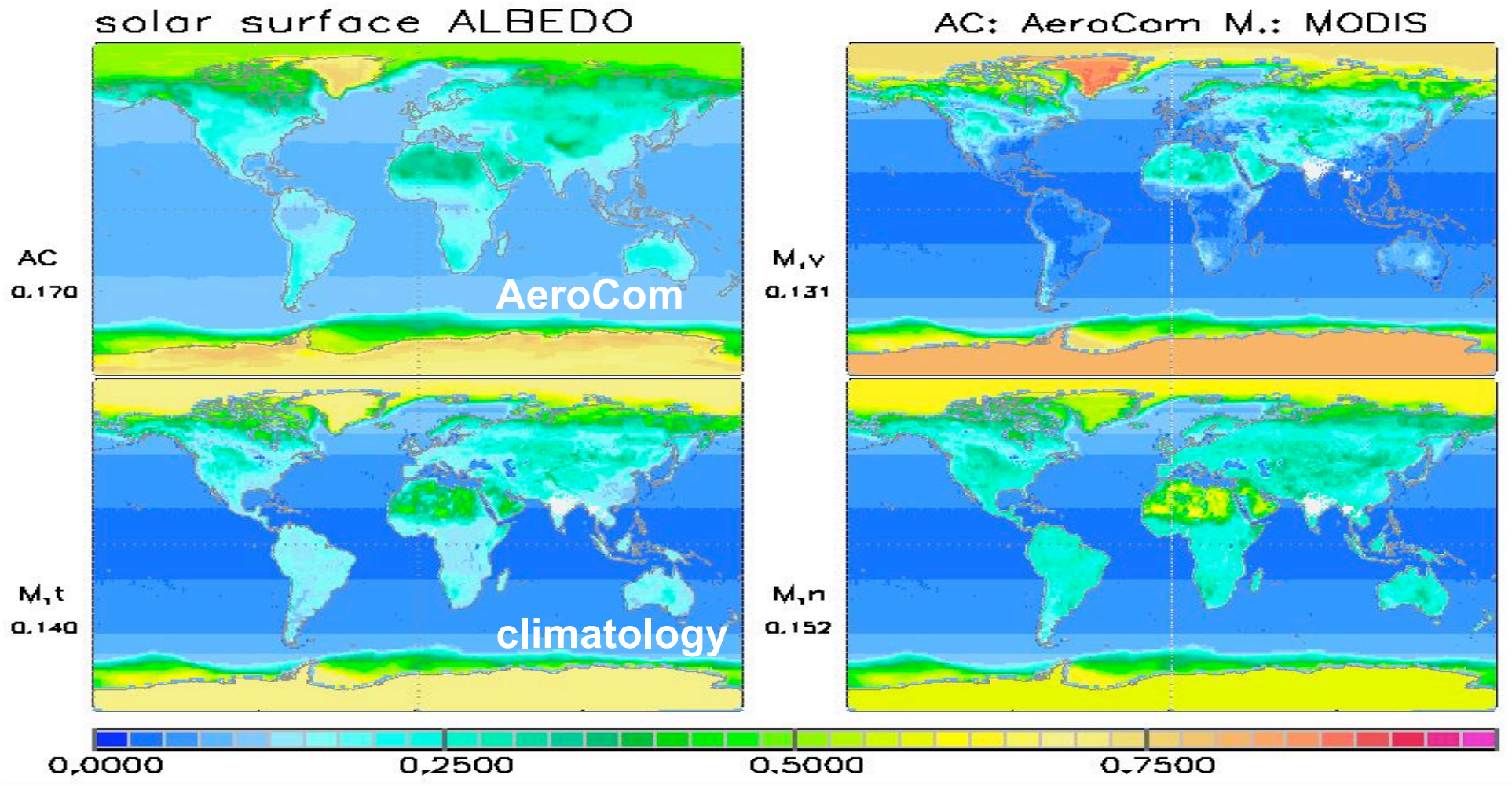
- aerocom total aot is lower – *contributing factor*
- aerocom ocean albedo is higher – *contributing factor*
- other explanations needed: a sub-sample issue?
  - aerocom (of 9 models), median (of 16 models)

total AOT – aerosol optical thickness



- off-line total aot is slightly larger than on-line

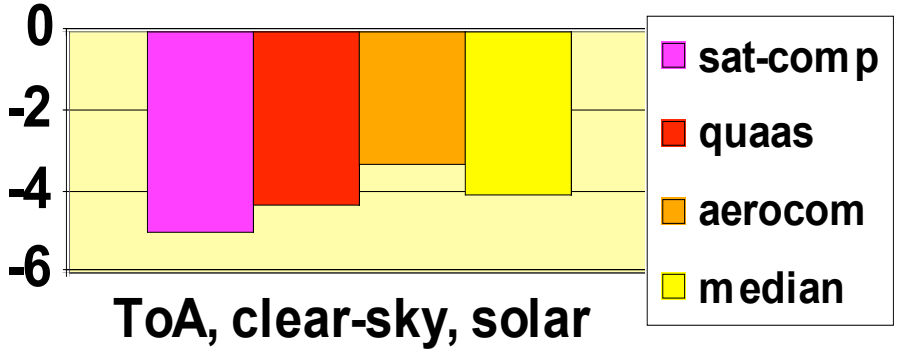
solar surface albedo

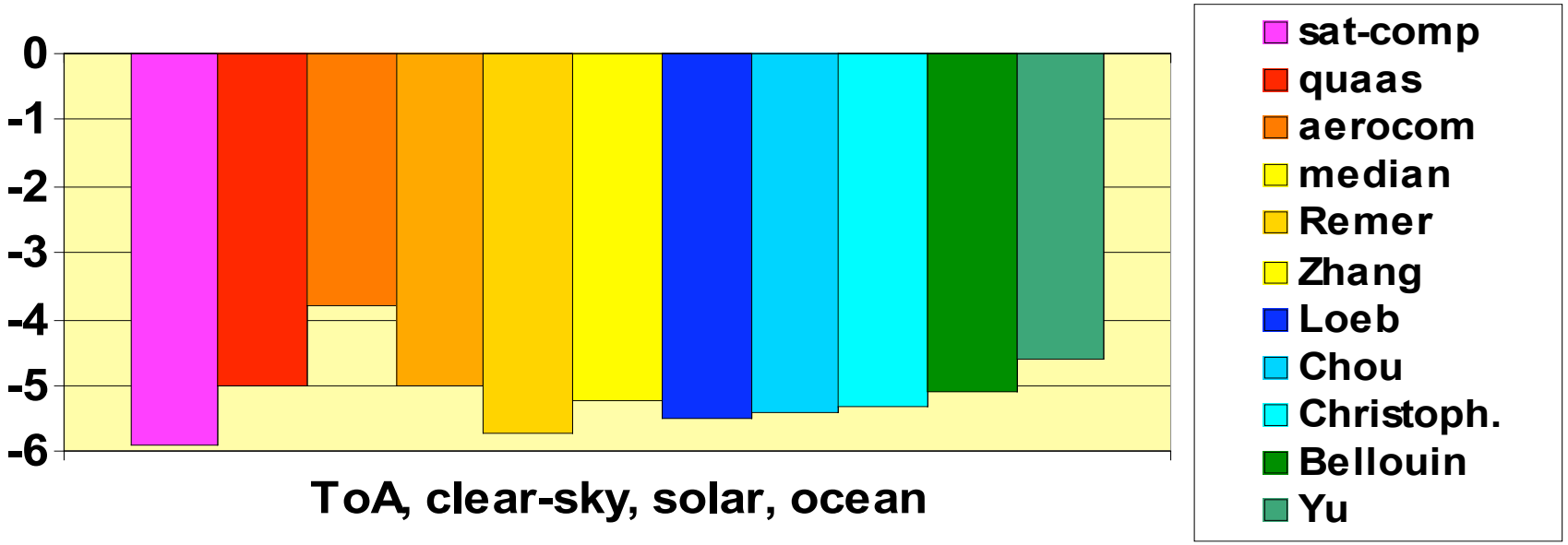


- off-line alb is smaller than on-line - except desert

global annual ToA forcings (W/m²)

- clr-sky, total, solar
  - ca - 4.5 W/m²
  - ca - 5.0 W/m² (oceans)





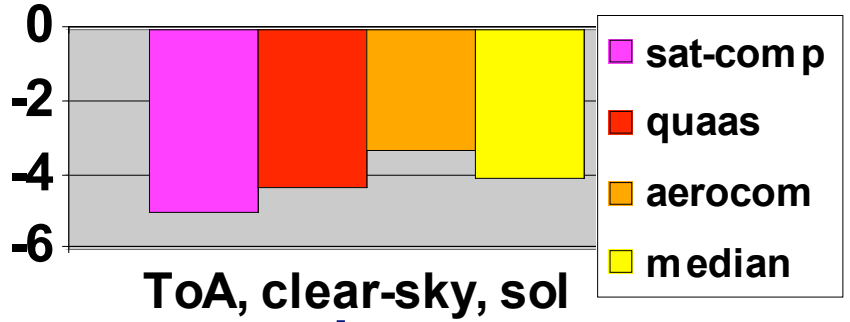
global ann solar ToA forcings (W/m²)

- all-sky, anthrop
- **complicating issues**
  - same anthrop fraction?
  - same cloud properties ?
  - same alt. placement?

lower aerocom F expected

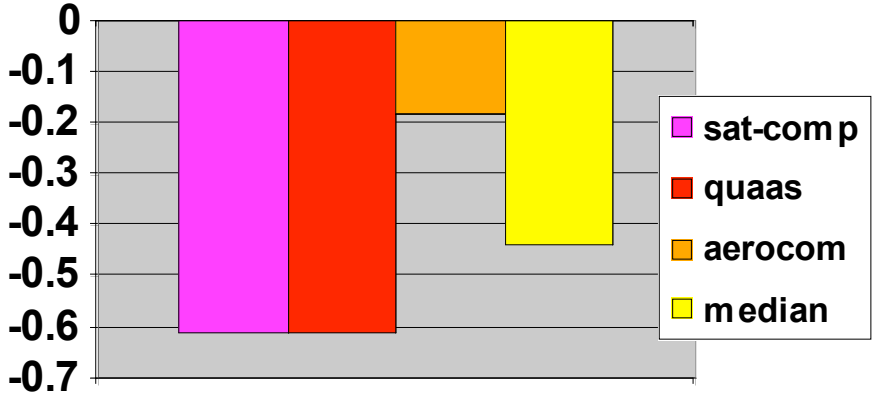
…but not that low !

- lower anthrop. aot
  contributing factor
- cloud cover?
- rel. higher (abs) aerosol?



ToA, clear-sky, sol

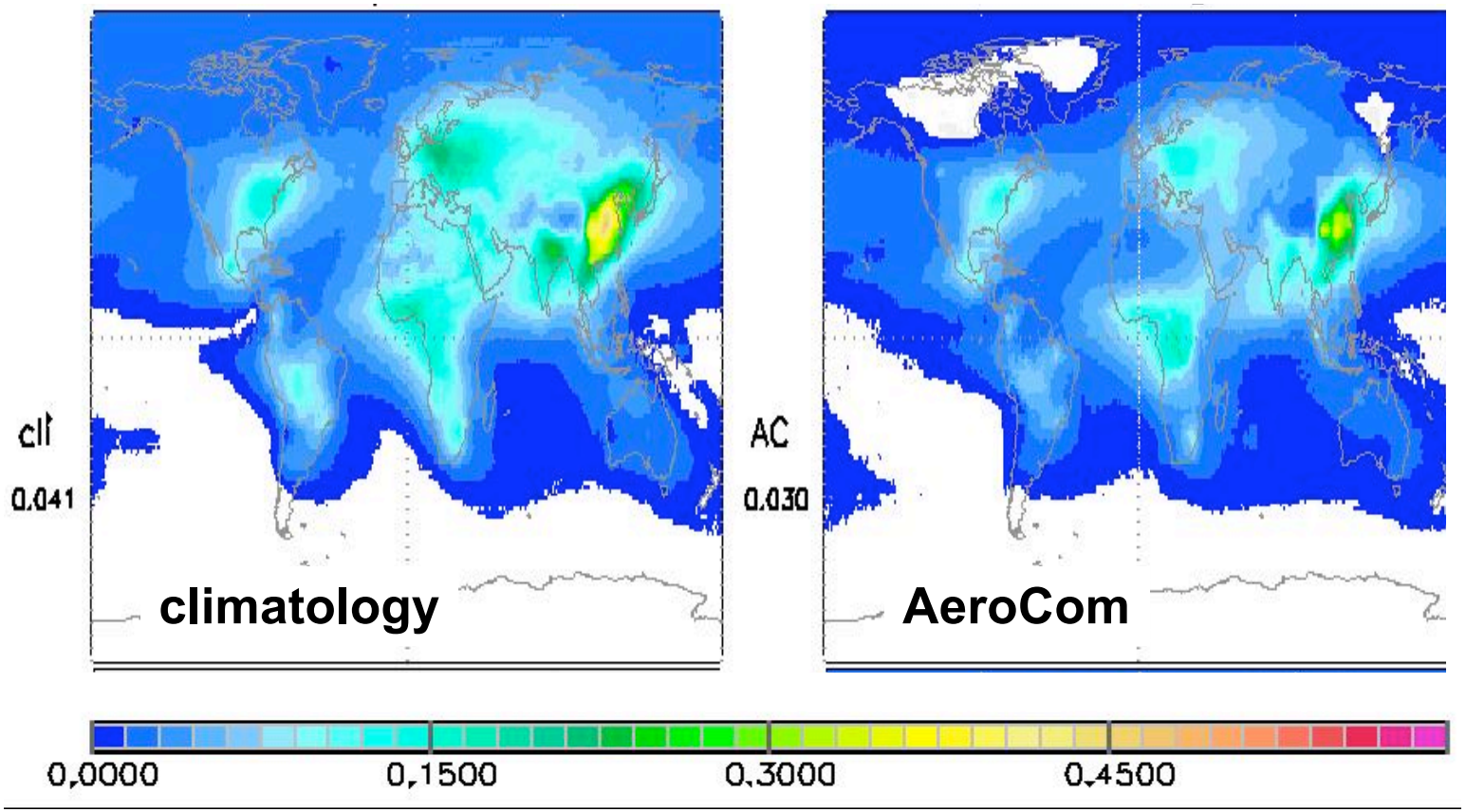
↓ ?



TOA, all-sky, s, antr

values refer to complete coverage (scaling with median for missing data)

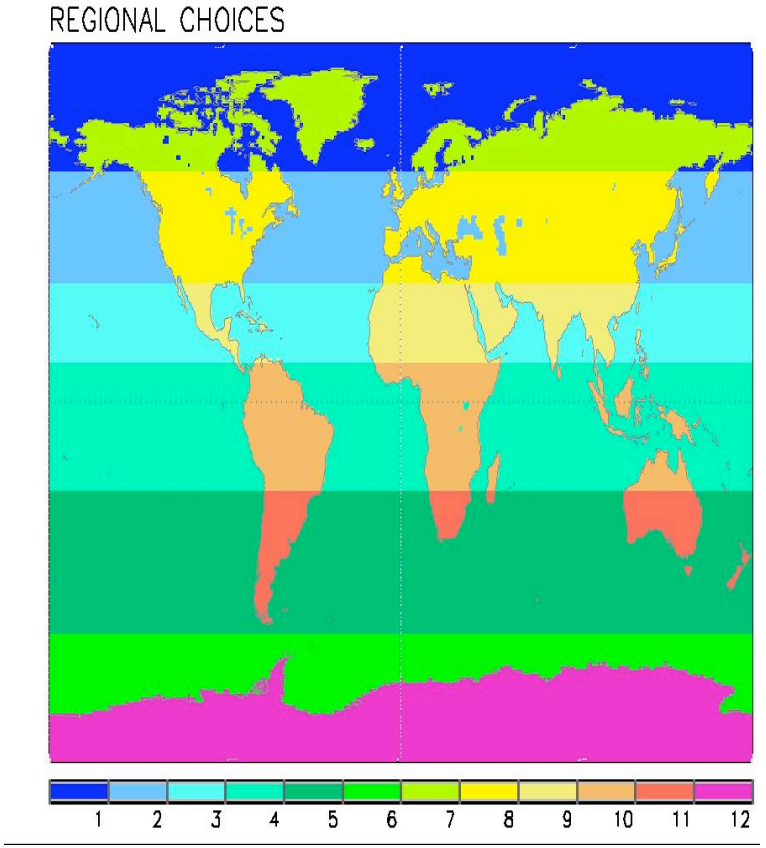
anthropogenic AOT



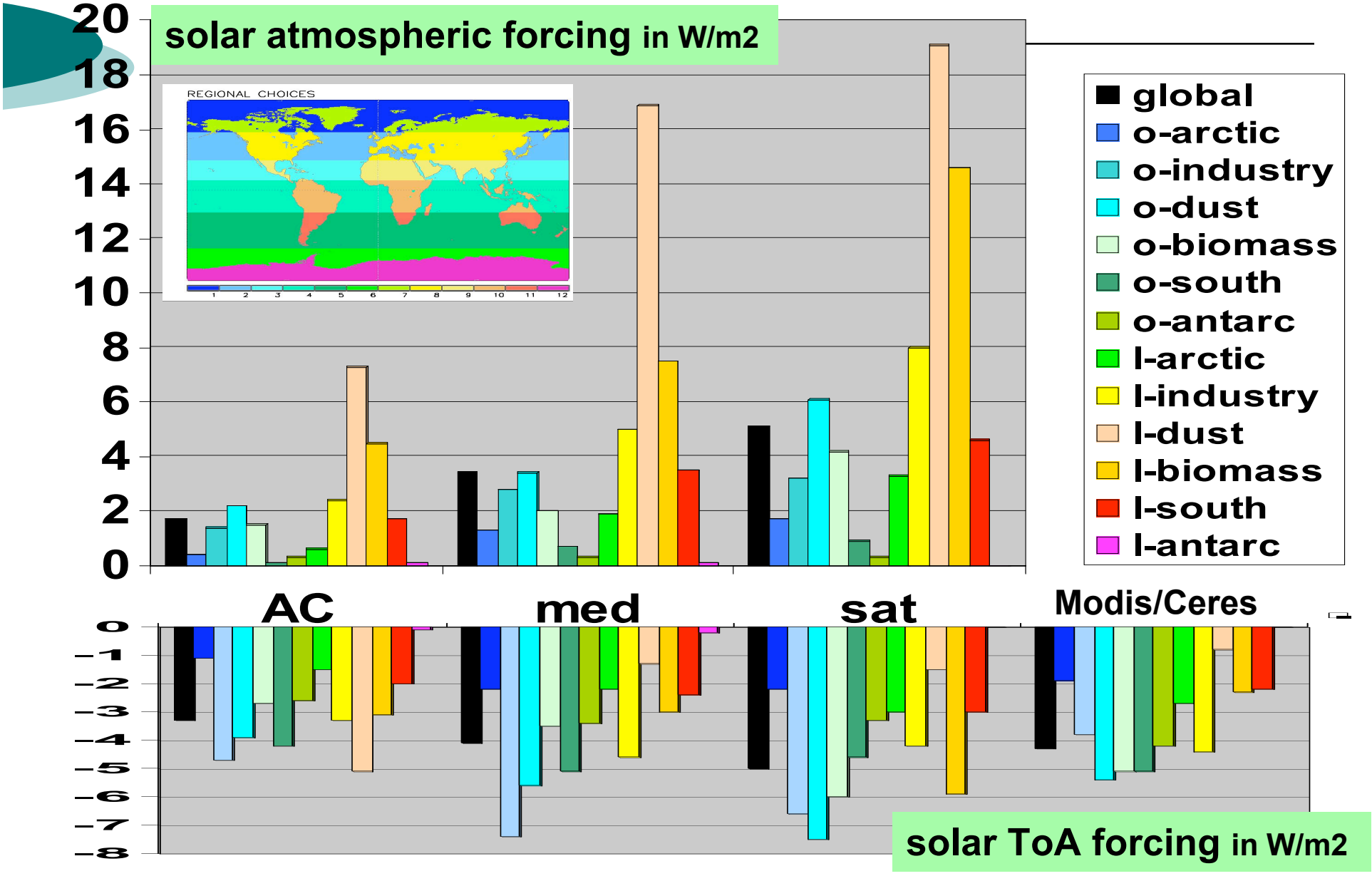
- off-line total aot is slightly larger than on-line

compare # 1 to # 4 regionally

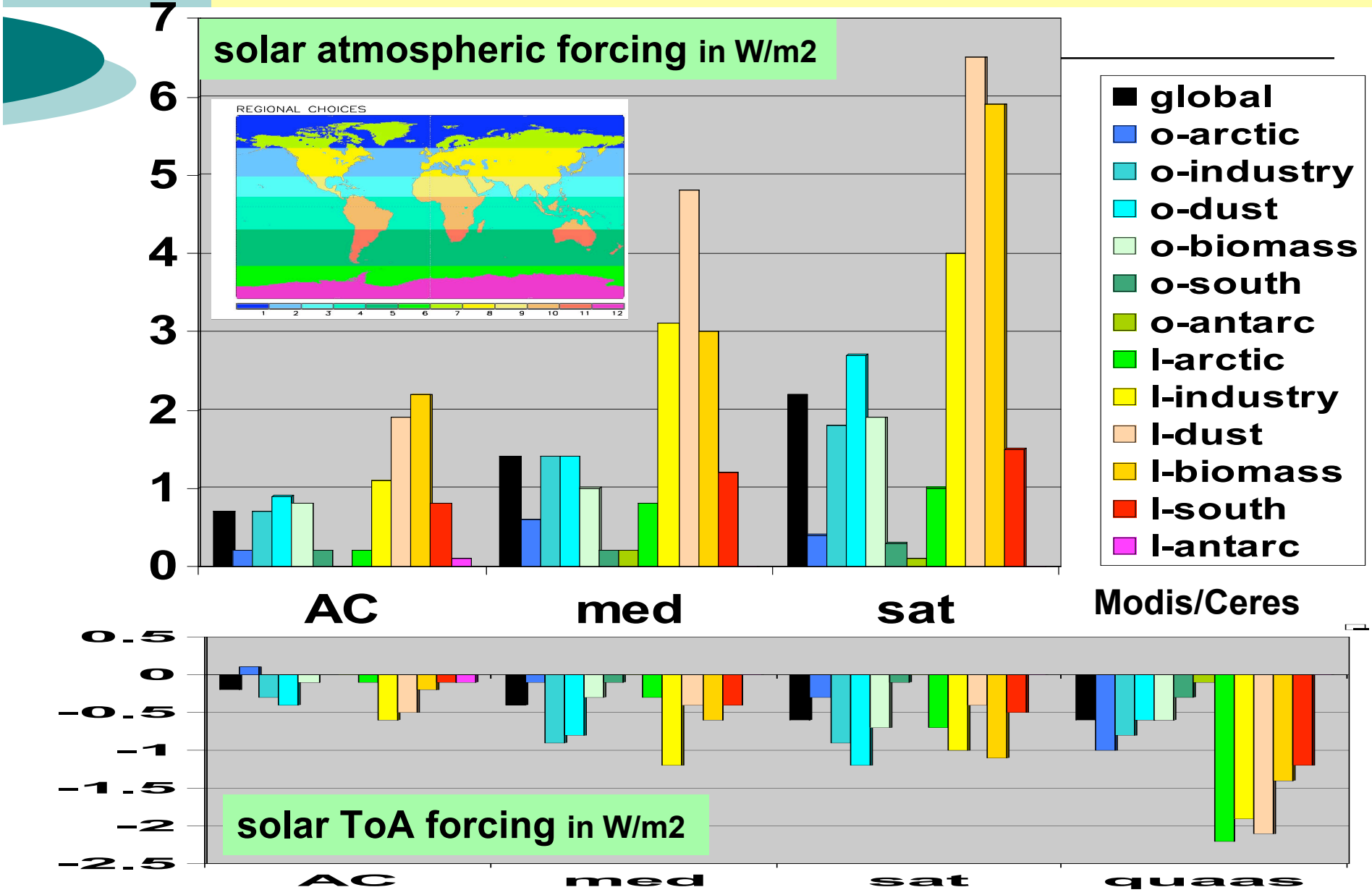
- separate the globe into 6 zonal regions
  - 90N-58N 3.8 | 3.8 Arctic
  - 58N-30N 9.0 | 8.4 industrial
  - 30N-10N 11.2 | 5.1 dust
  - 10N-22S 21.2 | 6.1 biomass
  - 22S-58S 21.2 | 2.5 southern
  - 58S-90S 4.9 | 2.7 Antarctic
- separate by surface type
  - Land %
  - Ocean %



regional total clear-sky forcing



regional anthro all-sky forcing



what we found

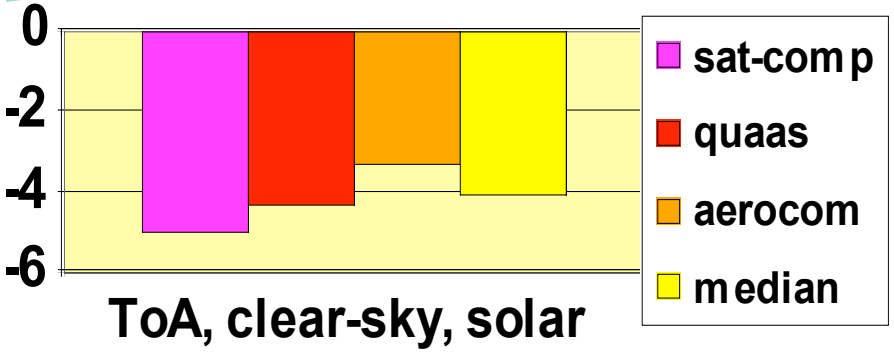
- the direct clear-sky ToA forcing is ca - 4.5W/m^2
  - very ‘robust’ at -5 W/m^2 over the oceans on average
- the aerosol direct all-sky ToA forcing (with relevance to climate) is significantly smaller and uncertain
  - values vary: 0.0 and -0.7W/m^2 (‘model’ < ‘data-tied’)
  - differences are largely introduced by composition!
    - without absorption diff. the gap between modeling and data-tied approaches would be even larger!
  - uncertainties to correctly place aerosol (Calipso?) and quantify the anthrop. fraction (contribute)

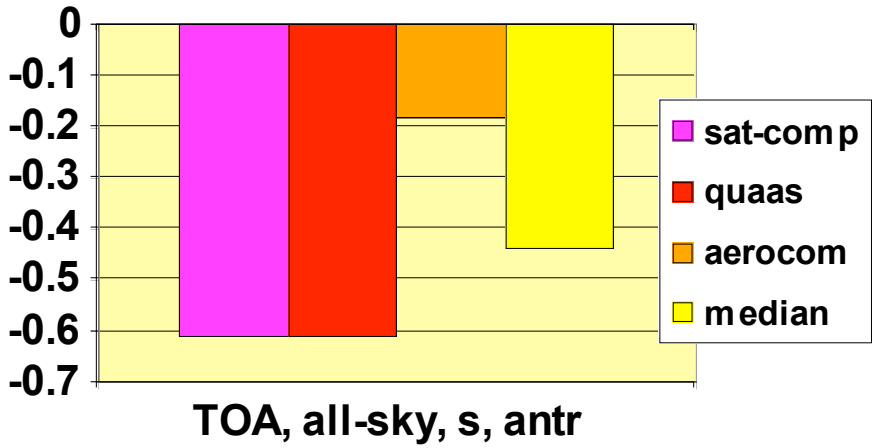
final thoughts

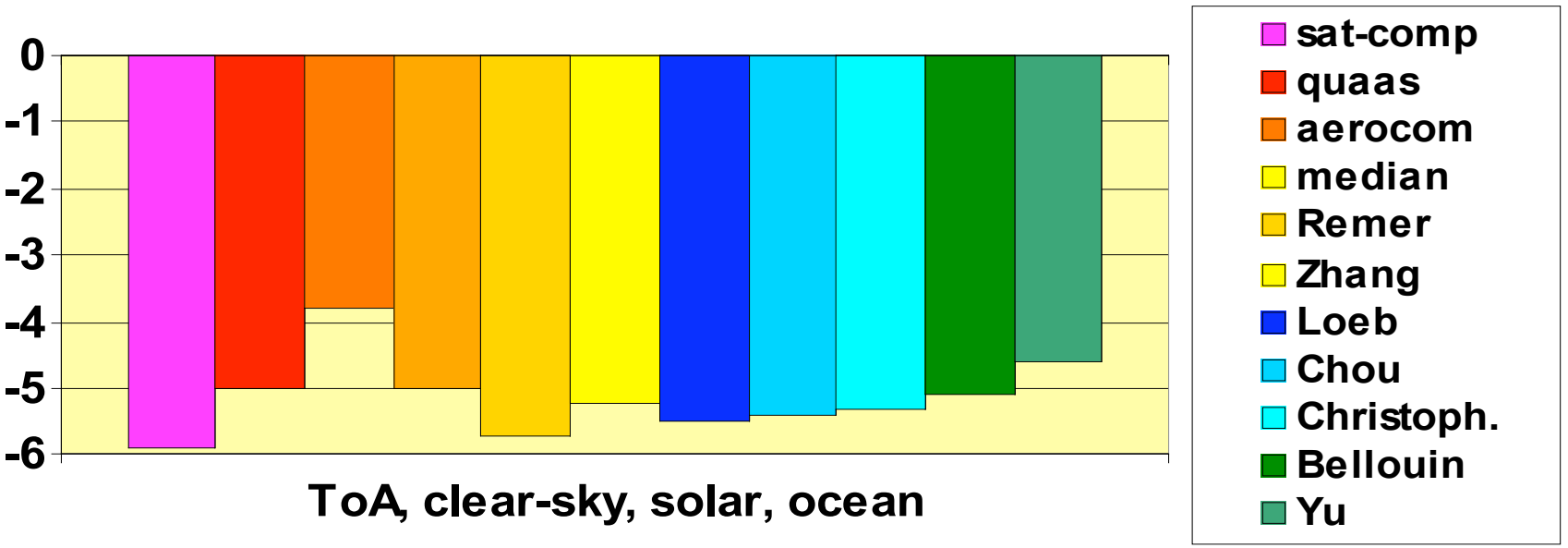
- estimation of the anthropogenic direct aerosol forcing at ToA is so difficult because:
  - we cannot measure anthropogenic fraction
  - we are uncertain on the absorbing properties
  - we are uncertain about the correct altitude placing
    - matters in the context of clouds (all-sky)
  - the overall impact is composed from differences of larger numbers
    - scattering vs absorption
    - solar impact vs infrared impact

extras

global annual ToA forcings (W/m²)







my estimate

for **the direct aerosol forcing**

at the top of atmosphere (ToA)
with clouds (all-sky conditions)
for anthropogenic aerosol